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FIRE IN U.S. ARMY HELICOPTER ACCIDENTS

1 JULY 1957 THROUGH 30 JUNE 1965

U.S. ARMY BOARD FOR AVIATION ACCIDENT RESEARCH

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FIRE IN UNITED STATES ARMY HELICOPTER ACCIDENTS

1 July 1957 through 30 June 1965

By
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Human Factors and Engineering Division
Human Factors Section

Report No. HF 67-1

THE U.S. ARMY BOARD FOR AVIATION ACCIDENT RESEARCH

USABAAR

COLONEL WARREN R. WILLIAMS, JR.
Director

INDEX

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SUMMARY: This report is a statistical review of 147* major helicopter fire accidents that occurred during the eight-year period of July 1957-June 1965. Findings of July 1962-June 1963 are compared with those of the subsequent two years to show tabular changes of similar periods. Findings of the first six-year period of FY 58-63 were reported in an earlier USABAAR study, "Army Helicopter Accidents Involving Fire."

The number of fire accidents increased during FY 64-65 from 94 to 147. During FY 64-65, fire was present in 15% of the major helicopter accidents, compared to 11% for FY 62-63. The fire accident rate per 100,000 flying hours ranged from a low of 1.25 in FY 61 to a high of 5.2 in FY 64. FY 65 showed a decrease of 4.3.

Ninety percent of fires in major accidents erupt on or immediately after the initial impact of the crash sequence. Post-crash fires demonstrate the urgent need to incorporate recent advancements made in the technology of flammable fluid containment in Army helicopters.

Seventy-two percent of the post-crash fires erupt in crashes in which the forces are judged to be within the limits of human tolerance. In 48% of the 106 survivable fire accidents, fuel spillage occurred. Fuel tanks and lines continue to fail and cause spillage.

Twenty-nine inflight fires were reported during FY 64-65. Twenty-seven (57%) of the 47 inflight fires for the eight-year period were classified as either precautionary or forced landings. Fourteen inflight fires were present in major accidents.

Fires account for 10% of the major accidents and are responsible for 44% of the injured and 72% of the fatalities in all major helicopter accidents.

Sixty-six percent of the occupants involved in major fire accidents were injured as compared to 11% in other types of major accidents. Thirty-five percent of the fire-accident occupants received thermal injuries.

The occupant survival rate in fire accidents is 64% as compared to 98% for nonfire major accidents. Thirty-five fatalities, 18 in survivable accidents, have been attributed to thermal injuries.

The cost of damaged and destroyed helicopters in fire accidents during FY 64-65 totaled eight million dollars. The total for the previous six years was 12 million dollars.

INTRODUCTION: An earlier USABAAR report of helicopter fire accidents concluded: "When fire erupts in an otherwise occupant-survivable accident, it is a grim reminder of the need to improve the crash-fire-worthiness design of these aircraft."[1] This report finds no reason to alter that statement. In fact, there is reason for even greater emphasis. The 117** fire accidents of FY 64-65 occurred during the period when the Army developed and deployed its air mobility concept. Much of that concept was developed using essentially the same helicopter inventory that made up the fire accident history related in earlier reports.

Tactical uses of the helicopter which have emerged have outmoded the criteria used in the crash-fire-worthiness design of that generation of helicopters. The data of the tables that follow justify an urgent need to update a criteria that emphasizes control of the spillage of flammable fluids. This updating process must look critically at the use of the helicopter in the mobility concept and the stresses of its tactical environment. A portion of this environment is portrayed in part in 21 different types of accidents in Table 4. The impact phenomena of hard landings, wire strikes, roll-overs, and rotor strikes of trees and terrain must be studied in the updating process.

The tables that follow show that 72% of post-crash fires erupted in crashes in which the forces of impact were judged to be within the limits of human tolerance. They also show that in 48% of the survivable fire accidents, fuel spillage has been the primary cause of fire. In these accidents, it was found that the fuel cells and plumbing immediate to it were unable to withstand the crash forces and resist penetrating punctures.

During the eight years this report covers, the fuel system of the OH-13G and H demonstrated the least resistance to failure during crashes. This observation helicopter, which has been one of the mainstays of Army operations, accounted for 38% of the survivable post-crash fire accidents. Its main design deficiency is the unprotected location of its twin fuel tanks (see Figure 2).

However, because of the success of a recent fuel tank modification, there are indications that OH-13G and H fire accidents will reduce significantly. At this time, all the G and H models are either in the process of modification, or have completed modifi-

**This report excludes analysis of 55 fire accidents of Vietnam, National Guard, and Reserve.*
***90 of these occurred in major accidents.*

cation that will increase the crash resistance of their fuel tanks. This modification, developed mainly for the G and H models, has also been applied to the S and T models purchased during this period. The modification is economical and relatively easy to accomplish. It requires wrapping each fuel tank with two layers of 13-ounce nylon and then brushing on several coats of a polysulphide rubber binder. The development and current success of the modification is reported in "There Was No Post-Crash Fire," AVIATION DIGEST, June 1966.

There are strong indications that in the future other models will show a much improved fire accident record. This research, conducted primarily by industry under the direction of the U. S. Army Aviation Materiel Laboratories, has been successful in the development of a highly efficient fuel cell material.[2]

During development tests, this material demonstrated its superiority over other materials to absorb energy before rupturing. Cells of this material installed in UH-1's, CH-47's, OH-6's, and others that come into or remain in inventory are expected to change the crash-fire picture of Figure 1 significantly. Equally important is the later development of a quick reacting coagulant to be used with this material in the construction of fuel cells. Already, this combination has proven its resistance to tear and puncture by demonstrating it can seal punctures while allowing minimum spillage.

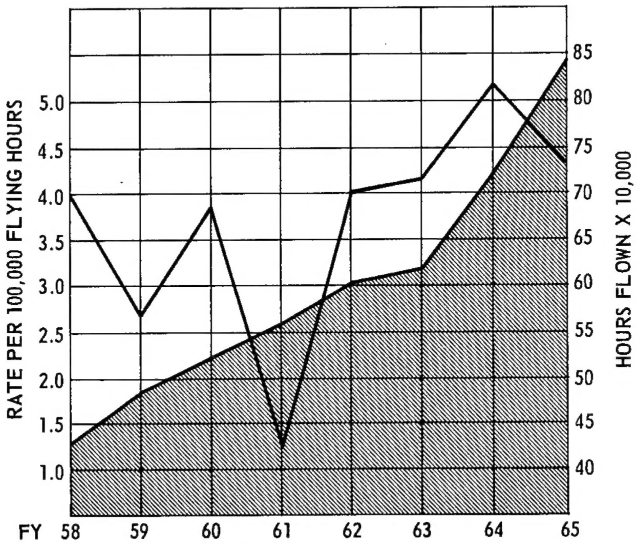
There is hope for even greater success that should virtually eliminate the occurrence of post-crash fires, even when crash forces approach the upper survivable limits of human tolerance. This goal will be achieved when the remainder of the fuel system, the routing lines and components are subjected to the same imaginative thinking that has been successful in the development of the fuel cell material. It will be achieved when the designer can assimilate and exploit the concept of controlled failure–the key to attenuating crash forces–into his design repertoire.

FREQUENCY AND NUMBER OF FIRE ACCIDENTS: Over the eight years of this report, the fire accident rate has varied from a low of 1.25/100,000 flying hours in FY 61 to a high of 5.2/100,000 hours in FY 64 (see Figure 1). The annual mean rate for the period is 3.7/100,000 flying hours. The rates of Figure 1 include the occurrence of fire in the classifications of accidents listed in Table 1. Note, however, that the rates of Figure 1 do not include 55 fire accidents listed in Table 1 as accountable to the National Guard, Army Reserve, and Vietnam operations.

It is clear in Figure 1, other than the abrupt drop in FY 61, that the increase in fire accidents tends to follow the increase in flying hours. Such a pattern was indicated in the data of earlier reports. There appears to be more than one reason for the

FIGURE 1

Helicopter Fire Accidents*
Rate vs Hours Flown
July 1957 - June 1965



*Excluding RVN, NG, and Reserve
—Fire Acdt Rate ▨ Hours Flown

parallel pattern. One apparent reason, as shown in Figure 1, is the correlation of exposure. With the increase of flying hours, the fire accident rate can also be expected to increase. Another reason which complements the first is the fact that essentially the same inventory of helicopters has been in use throughout the period. The inventory has increased in total number, new series have been added to old models, and even two new models, the UH-1 and CH-47, have been added, but nothing has changed in terms of making these models more crash-fire-worthy. The addition of the UH-1D and CH-47 late in the period has had no apparent effect on the fire accident pattern. Neither of these models, though the UH-1 has earned a comparatively good fire accident record, incorporate any major advances in crash-fire-worthiness design.

At least two indications account for the fire accident rate of FY 61, which dipped to the record low of 1.25/100,000 flying hours. One is the fact that FY 61 also had the lowest number of major accidents. From an accident point of view, it was the safest of the eight years. Though flying hours continued a steady increase in FY 61, only 134 major accidents were recorded. There were 193 in FY 60 and 204 in FY 62. The other significant indication of FY 61 is that it also had the lowest percentage of fires per major accident. The percentage decreased from 7.3% of the previous year to 3.7%. In FY 62, the percentage climbed to 10.8%. This has been exceeded each following year.

From the accident information available to USABAAR, it is virtually impossible to fully explain

TABLE 1

Occurrence of Fire in Army Helicopter Accidents
July 1957 - June 1965

FY	TOTAL	FIRE BY ACDT CLASSIFICATION MAJOR	MINOR	INCIDENT	F/L	P/L	FIRE IN FLIGHT	FIRE IN POST CRASH	FIRE EXPERIENCED BY N.G. & RESERVE	FIRE EXPERIENCED IN RVN
65	65	51	0	4	2	8	14	51	2	27
64	52	39	1	3	7	2	15	37	4	11
63	32	27	1	2	2	0	5	27	2	4
62	27	25	0	1	1	0	4	23	2	1
61	7	6	0	0	1	0	1	6	0	0
60	21	16	1	1	3	0	6	15	1	0
59	14	14	0	0	0	0	0	14	1	0
58	17	16	0	0	1	0	2	15	0	0
	235	194	3	11	17	10	47	188	12	43

(other than through the above indications) why the occurrence of fire in the major accidents of FY 61 was less than any other year. It has been found that the CH-34, CH-21, and OH-13G and H, which through FY 63 accounted for 67% of the fire accidents, accounted for only two of the six major fire accidents of FY 61. Also during the year FY 61 these aircraft did not decrease their exposure to the occurrence of a fire accident. They logged more than half of the 560,000 hours flown.

INFLIGHT FIRE EXPERIENCE: Past reports did not emphasize the occurrence of inflight fires, mainly because of the urgency to reduce the number of post-crash fires that dominated the helicopter fire accident picture. Table 1 data show inflight fires increased significantly during FY 64 and FY 65. During these two years, 29 (62%) of the reported 47 inflight fires occurred.

It is important to know that though each of these inflight fires had the potential to cause damage sufficient to be classified as a major accident, only 14 (30%) were so classified. Twenty-seven (57%) were classified as forced or precautionary landings accomplished without damage or injury.

The maneuverability of the helicopter which enables it to land in confined locations and to use unprepared landing surfaces is the factor responsible for minimizing what could otherwise be the tragic and costly result from inflight fires. Inflight fires were confined and small because the time between detection and getting into position to fight the fires could be kept to the minimum. Once on the ground, the hand-operated fire extinguisher carried aboard the aircraft was effective in a majority of these cases.

The origin of inflight fires, given primarily in terms of its location, is indicated in column B of Table 3. Fire sources varied from shorted circuits, belching flames, or spewing of hot metal from a failed or malfunctioning engine. It is significant that fuel systems, particularly fuel cells, were not primarily involved. The integrity of main fuel systems in these fires is the key factor that provided the time needed to execute a landing. The events of inflight fires, their detection, and successful confinement are described in these selected briefs:

"UH-19D–Cockpit filled with smoke. A ratching noise was heard. Autorotation was made. Found transmission oil cooler belts were burning due to bearing seizure."[3]

"CH-34A–After descending from 4,000 feet, engine roughness was noted. Fire was seen coming out of exhaust stack. Fuel and engine switches were turned off. Aircraft landed immediately. Found Nr. 1 cylinder cracked."[4]

"CH-37B–Tower personnel reported smoke spewing around transmission deck shortly after takeoff. Aircraft landed immediately. Fire caused by oil cooler fan belts."[5]

Though Figure 1 shows a yearly increasing rate, perhaps the inflight fire part of that picture may not be a valid one for each of the eight years. The trend, particularly the increase since FY 61, may in part be due to improved reporting. Changes to AR 385-40 which require reporting of incidents and precautionary landings, plus the increased awareness of aviation units, probably has had this effect. Following is a brief of an inflight fire that probably would not have been reported to USABAAR prior to FY 61.

"OH-13S–Pilot smelled smoke coming from the collective pitch stick. Short circuit in wiring. Disconnected wiring and continued flight."[6]

As shown in Table 1, Vietnam operations have increased inflight fires. Seven of the FY 64 and FY 65 inflight fires, of which four resulted in major accidents, happened in that theater. Enemy gunfire started the inflight fire in five of these seven.

FIRE ACCIDENTS AND HELICOPTER MODEL: The helicopters and their fire accident record responsible for the rates and trends shown in Figure 1 are listed in Table 2.

TABLE 2

Fire and Non-Fire Accident Experience by Model
July 1957 - June 1965

	FY 1958-1961				FY 1962-1963				FY 1964-1965				CHANGE FY 1962-1965	
			FIRE-IMPACT SURVIVABLE				FIRE-IMPACT SURVIVABLE				FIRE-IMPACT SURVIVABLE			
AIRCRAFT	MAJOR ACDTS	FIRE ACDTS	NO.	RATE	MAJOR ACDTS	FIRE ACDTS	NO.	RATE	MAJOR ACDTS	FIRE ACDTS	NO.	RATE	FIRE AT IMPACT	FIRE AT IMPACT-SURVIVABLE
OH-23	133	9	5	1.1	78	3	2	6	79	9	7	1.5	6	5
OH-13G,H,K	178	13	11	2.9	116	20	15	6.4	46	9	7	6.0	-11	-8
OH-13D,E	104	2	2	1.0	37	3	3	3.4	23	1	1	1.5	-2	-2
OH-13S,T	NOT IN INVENTORY								23	2	2	4.3	2	2
CH-34	80	8	6	1.5	31	7	4	2.1	26	6	6	4.3	-1	2
CH-21	118	9	5	1.8	46	5	2	1.6	21	4	2	2.5	-1	0
UH-19	72	4	3	1.4	29	3	2	1.7	27	3	3	1.9	0	1
UH-1A,B	22	3	2	5.3	51	3	2	1.4	77	12	7	1.1	9	5
UH-1D	NOT IN INVENTORY								23	6	5	4.9	6	5
CH-47	NOT IN INVENTORY								5	2	2	10.5	2	2
CH-37	0	2	1	2.6	11	0	0	0.0	5	1	0	0.0	1	0
TOTAL	716	50	35	1.7	399	44	30	2.5	355	55	42	2.7	11	12

149 aircraft involved, 147 major fire accidents, 2 mid-air collisions-four aircraft involved

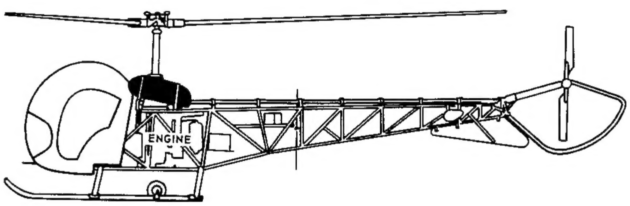


FIGURE 2

OH-13 Models G and H Twin Fuel Cells

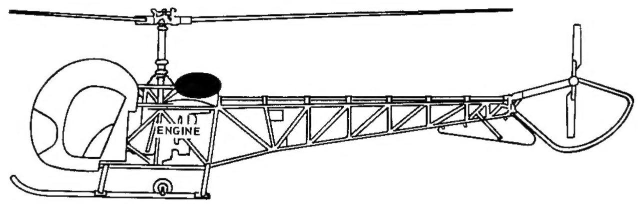


FIGURE 3

OH-13 Models D and E Single Fuel Cell

Note that data of Tables 2 through 10 do not include the fire accidents of the National Guard, Army Reserve, or those in Vietnam. The fire accidents of these activities were not used, principally because information reported from these sources varies considerably from that received from other operations. Understandably, these activities, due to lack of time, manpower, or clerical support, are often unable to conduct thorough investigations or prepare reports in the detail needed. In Vietnam, it is not unusual for an accident to occur in an unsecured area.

Fire accidents caused by enemy fire, though pertinent to the objectives of this report, are not included. This omission does not mean that USABAAR is not interested in the fire problem due to enemy action. It is believed, however, that the omission of the 55 fire accidents from these sources will not appreciably affect the purposes of this report. The analysis of this report then pertains to 77% of the 235 fire accidents included in Table 1.

To aid in the analysis of the fire problem, the data of Table 2 relate the fire and major accident experience to specific models, and, for some models, a specific series. Perhaps the most revealing data of Table 2 are the rates at which fires occur in survivable accidents. These rates, derived from eight years of experience, are now beginning to show the crash-fire-worthiness of each model.

For purposes of this study, a survivable accident is one in which the crash forces imposed on the occupant are within the limits of human tolerance and some portion of the inhabitable area of the aircraft remains reasonably intact. The definition accepts that the limits of human tolerance to crash forces in an exact sense are still essentially unestablished. Also, the difficulty of computing G forces involved in a helicopter accident is recognized. These reservations of the definition are nullified somewhat by the method used in determining the classification. Classification of these accidents has been determined by the flight surgeon who served as a member of the investigating board. His professional competence, evidence found at the accident scene, and subsequent information uncovered during the investigation, determine whether an accident is classified as survivable or nonsurvivable.

The ultimate goal of crash-fire-worthiness design is to prevent fire in all survivable accidents. To achieve this goal, crash-fire-worthiness must play a role in the initial design, the plans for growth, and in the design of modifications that normally follow. Otherwise, when performance is increased, advanced models and series are developed and when extensive modifications are made, the changes necessary are often made at the expense of crash-fire-worthiness features.

The growth of the OH-13 and how its growth affected its fire accident record is a case in point. For example, data of Table 2 show the OH-13D and E have achieved one of the better survivable fire accident rates of all models listed. It has had only six fires in 164 major accidents during the eight years. During FY 64 and FY 65 its record shows only one fire, and that one occurred when oil from the broken engine sump ignited.

The reason for the OH-13D and E low rate, now that it can be compared with the G and H, is believed to be due to its single 29-gallon tank, mounted above the engine and aft of the rotor mast (see Figure 3). In this location, the tanks are relatively well protected from rupture and puncture damage. However, Table 3 shows that in five of its six fire accidents, either the tank or the adjoining fuel lines failed to prevent fuel spillage. This fact points out that this location is still not ideal, because, when fuel is spilled, it has quick access to the many ignition sources available about the engine.

The survivable fire accident rate of the OH-13G and H over the years has been five times that of the D and E. In 91% (32 of 35) of the survivable fire accidents shown on Table 3, fire was due to a rupture or puncture of the fuel tanks or fuel lines. Added fuel capacity, needed for the D and E to grow into the higher performing G and H, required larger tanks. The change resulted in the design decision to install twin tanks with a combined capacity of 43 gallons. This new location was needed for the enlarged tanks because it would least affect the helicopter's center of gravity (see Figure 2). The enlarged twin tanks in this location, saddled on each side of the rotor mast above the engine, crowded the available protective space the airframe gave to the D and E tank. Because of their enlarged size, the twin tanks were moved nearer the rotor mast and

TABLE 3

Cause - Location of Fire by Model
July 1957 - June 1965

AIRCRAFT	RUPTURED FUEL CELLS/LINES A	RUPTURED FUEL CELLS/LINES B	ENGINE MALFUNCTION A	ENGINE MALFUNCTION B	ELECTRICAL SYSTEM A	ELECTRICAL SYSTEM B	CARBURETOR/LOOSE FUEL LINES A	CARBURETOR/LOOSE FUEL LINES B	FUEL VENTS/LINES A	FUEL VENTS/LINES B	LOOSE FUEL TANK CAP A	LOOSE FUEL TANK CAP B	ENGINE OIL SYSTEM A	ENGINE OIL SYSTEM B
OH-23	6	0	2	1	1	1	2	0	1	0	0	0	0	0
OH-13G,H	31	0	0	0	0	0	0	0	1	0	1	2	0	0
OH-13D,E	5	0	0	1	0	0	0	0	0	0	0	0	1	0
OH-13S,T	1	0	1	0	0	1	0	0	0	0	0	0	0	0
CH-34	9	0	2	3	0	0	1	0	1	0	0	0	0	1
CH-21	7	0	2	3	0	2	0	0	0	0	0	0	0	0
UH-19	5	0	2	3	0	3	0	0	0	1	0	0	0	0
UH-1A,B	3	0	2	3	0	1	0	0	1	1	0	0	0	0
UH-1D	0	0	2	2	1	1	0	0	1	0	0	0	0	1
CH-47	0	0	1	0	0	0	0	0	0	0	0	0	0	0
CH-37	1	0	0	2	0	1	1	0	0	1	0	0	0	1
TOTAL	70	0	14	18	2	10	4	0	5	3	1	2	1	3

AIRCRAFT	TRANSMISSION OIL SYSTEM A	TRANSMISSION OIL SYSTEM B	HYDRAULIC SYSTEM A	HYDRAULIC SYSTEM B	ROTOR CLUTCH A	ROTOR CLUTCH B	HEATER/ENGINE EXHAUST A	HEATER/ENGINE EXHAUST B	FIRE DUE TO EXTERNAL SOURCE A	FIRE DUE TO EXTERNAL SOURCE B	UNDETERMINED OR NOT REPORTED A	UNDETERMINED OR NOT REPORTED B
OH-23	0	0	0	0	1	1	1	0	0	0	0	0
OH-13G,H	0	0	0	0	0	0	0	0	0	0	0	0
OH-13D,E	0	0	0	0	0	0	0	0	0	0	0	0
OH-13S,T	0	0	0	0	0	0	0	0	0	0	0	0
CH-34	0	0	1	0	0	0	0	0	1	0	0	0
CH-21	0	0	0	0	0	0	0	0	0	0	0	0
UH-19	0	1	1	0	0	1	0	0	0	0	0	1
UH-1A,B	0	0	1	0	0	0	2	0	0	0	1	0
UH-1D	1	0	0	0	0	0	0	0	0	0	0	0
CH-47	1	0	0	0	0	0	0	0	0	0	0	0
CH-37	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL	2	1	3	0	1	2	3	0	1	0	1	1

A - Major Survivable Accidents B - Forced Landing, Precautionary Landing, Incident (Survivable)

were often punctured by the swash plate when the mast became displaced during a crash. Larger dimensions also caused the tanks to extend beyond the protection of the airframe, which makes them among the first parts of the aircraft to strike the ground. In the event of roll-over, which is characteristic of a helicopter accident, the twin tank configuration always leaves one tank atop to leak fuel. This point is illustrated by the following excerpts of statements given in two accidents:

". . . engine stopped immediately and the helicopter completed impact on its right side. The passenger got out first and discovered gasoline leaking down onto the hot exhaust pipe. The aircraft started to burn immediately . . ."[7]

The extreme position of a roll-over is not always required. In the following accident, an incline of 6.5° was sufficient.

". . . landed the helicopter on a slope, which was later measured as 6.5° laterally from right to left skid and 1.2° downhill from rear to front. The engine was not shut down. Approximately two minutes had now elapsed. In this time, fuel level from the right (uphill) tank was flowing through the connecting line into the left (downhill) tank, filling it. At this time, the passenger glanced over his left shoulder and saw fuel spraying out from around the fuel cap. The aircraft burst into flames . . ."[8]

Fortunately, by the time the OH-13 growth extended to the S and T series which needed even larger twin tanks mounted in the same location as the G and H, the wrapped tank modification to increase their crash resistance was becoming available. The T, for example, purchased later in the period, came with the modification complete, while a number of the S's had to be modified after going into operation.

As best it could be determined from the accident investigation reports, the tanks of eight of the 21 OH-13S's involved in major accidents were modified. The two fire accidents experienced during FY 64-65 did not involve those equipped with wrapped tanks.

In one instance a fuel tank failed. In that accident,[9] when the helicopter rolled over following a hard landing, the right tank struck the ground in the area of the forward baffle. Two slit-like ruptures were produced. Minimal leakage occurred because the aircraft was practically out of fuel. A small exhaust stack fire did follow. It was caused by fuel leaking from the tank interconnections failing near the upper tank. The fire from this source then spread to dry grass beneath the helicopter.

The other fire also followed a roll-over which, in this case, did not cause the tanks or connections to fail. In this accident, fuel in the turbo-supercharger ignited from its high temperature.

The earlier study gave an indication that because of the protective location of the UH-1A and B fuel cells (see Figure 4), these would be expected to earn a low fire accident rate. The UH-1A and B experience of FY 64-65 shows the lowest rate of all models at 1.1/100,000 flying hours. In its seven survivable fire accidents, the fuel tanks neither ruptured nor punctured. They remained intact and no fuel was spilled.

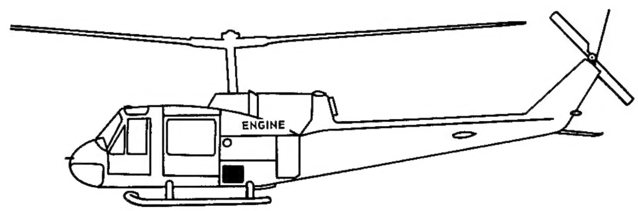


FIGURE 4

UH-1 Models A and B Bladder-Type Fuel Cells Aft of Cockpit

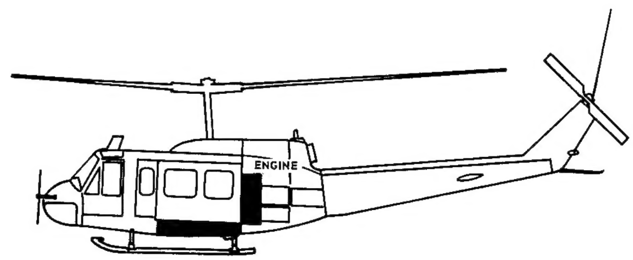


FIGURE 5

UH-1D Model Added Cells Aft of Cockpit

The record of the UH-1D which has a larger fuel capacity than the A and B, shows that the cells remained intact in four of its five survivable fire accidents. In the one accident,[10] leaking fuel from the ruptured tank did not get involved in the fire. The engine fire that erupted was put out with portable fire extinguishers before the fuel from the ruptured tank was reached. The UH-1D rate indicated in Table 2 of 4.9/100,000 flying hours is attributed to engine malfunction, the electrical system, and transmission oil system. The fuel system was indicted for the cause of one because of the improper design of its vent system.

The first six years of this period show the CH-34 had achieved one of the lower survivable fire accident rates. For these early years it had a rate of 1.8/100,000 flying hours, then increased abruptly because of six survivable fire accidents, to 4.3/100,000 flying hours. Over the years, as during the past two years, fire in this aircraft erupts because the landing gear is in position to penetrate the fuel

cells. The fuel cells, located below the fuselage floor, are susceptible to puncture upon impact and the near proximity of the forward fuel cell to the engine compartment. Each of these features, examples of inadequate crash-fire-design, are apparent in the following briefs:

"The left main gear was forced upward by the impact and punctured the left side of the aft tank. Subsequent pitching motion caused fuel from the punctured tank to splash forward making contact with either the engine exhaust or the engine itself, causing the fire."[11]

"When making a hard touchdown, the right gear collapsed, the aircraft rolled to its right, slid across the highway, caught fire, and burned. A wall of fire rapidly separated the pilot's compartment from the passenger area. The helicopter filled with smoke and fumes."[12]

Similar design practices are found in the UH-19, CH-21, and CH-47. In the Chinook (CH-47), however, this combination of features is somewhat better (see Figure 7). The fuel cells, though located below floor level, can be penetrated by the rear landing gear, but are some distance from the engines which are mounted on each side of the aft rotor pylon.

FIRE CAUSE AND LOCATION: The role fuel spillage plays in helicopter accidents is emphasized in this report (see Table 3). Fuel spillage occurred in more than two-thirds of the fire accidents. The table also shows that fuel spillage caused fire in 48% of the survivable fire accidents.

The data of this report suggest that the fuel spillage problem is attributable in part to the continuance of the designer to use, and the buyer to accept, fuel system design criteria developed exclusively for fixed wing aircraft. As a result, aviation has had to wait until the Army's intensive use of the helicopter to add the crashworthiness requirement to the designer's chore, and to make it a buyer's requirement. Because of this rather recent emphasis, the designer is now hearing the phrase, "fluid containment concept," and he is watching the developments of the technology being directed to make the concept a reality. There are favorable indications now that major advances will have been made before the next eight years pass.

The following description of a CH-47 inflight fire accident is typical of the information used to develop Table 3. In this case, the cause of the fire, as indicated in Table 3, was the transmission oil system.

"A restricted return oil line caused an abnormal amount of oil to accumulate in the engine transmission. The oil temperatures increased above its vaporizing temperature of 350°F. Oil vapor came out of the breather. The oil vapor ignited upon contact with the metal of the transmission gear box. The fire progressed through the drive shaft housing into the aft pylon where it was moved by the oil cooler fan through the aft section of the pylon."[13]

The engine and its accessories are next in order, after the fuel system, as the most frequent location of fire. Data of Table 3 show the engine was named in 14 major accidents and 18 times in fires of lesser classification. Sixty percent of this experience included four helicopters, the CH-34, the CH-21, the UH-19, and the UH-1A and B. Each model experienced five engine fires.

Engine fires seem to vary with the type of engine involved. The turbine engine, for example, simple in design, tends to confine many of its fires to the area of the gas producer, and aft to the tail pipe. Only rarely has it been reported that flame has spewed from the forward intake section, nor has there been a report involving its accessories and connecting lines.

These briefs of turbine engine fires reveal their nature.

"UH-1B major accident–Pilot turned off all switches and shut the engine down. There was a brief engine fire, extinguished immediately by the crash crew. The fire was apparently caused by sparks from the exhaust pipe."[14]

"UH-1A incident–On pickup to hover, pilot heard a loud explosion, followed by engine failure. Burning fuel coming out of the exhaust caused grass to catch fire, scorching the underside of the aircraft. Cause of failure is suspected to be failure of the linkage from the collective pitch to fuel governor, which allowed the engine to overspeed."[15]

The reciprocating engine, in contrast, appears to have many more points of ignition and flammable fuel sources. When failure occurs, whether it is a clogged supercharger drain valve, an improperly tightened exhaust manifold clamp, loose fuel lines, or blown cylinder, the probability of fire tends to be high. Usually in these cases the accident will read:

"UH-19D forced landing–A quick drop in manifold pressure was noticed, followed by a change in the sound of the engine. A vibration and then a hissing sound followed. Flames and smoke came from the left side of the engine, caused by failure of the Nr. 3 cylinder and piston assembly."[16]

The increase in electrical fires in recent years, plus the fact that 10 of the 12 occurred in flight, makes them worthy of mention. Fortunately, none of the 12 caused a major accident. Six, however, caused forced or precautionary landings to be made. The inflight electrical fires were due mainly to shorted circuits, sticking relays, and generator failures. The UH-19, more than any other model, had three electrical fires. One fire in the cockpit was caused by a short circuit in the attitude indicator. Failure of the starter relay to disengage caused the other two.

UH-1B and UH-1D batteries produced two post-crash fires following major accidents. In the B model[17] the battery fell out and ignited dry grass. Fire in the D model[18] battery compartment started some two minutes after the accident when the air-

craft was at rest. The hand extinguisher was used successfully in each case.

Hydraulic fluid was involved in three fires. In each case, the failure of the hydraulic system which resulted in fire was not a causative factor of the accident. These cases bring up the need to consider a hydraulic fluid with a flash point above the 200°F currently specified in MIL-H-5606. It could be suggested to use a hydraulic fluid that has a flash point at least equal to the 400°F of lubricating oil, MIL-L-7808. If a higher flash point fluid had been in use in either of the following accidents, fires would not have occurred.

"UH-19D—A loud noise was heard. Pilot executed forced landing procedure and entered autorotation. At touchdown, the aircraft landed hard on the right main gear and turned 90° to the right, shearing both nose gear. As the right gear sheared, the oleo strut ruptured, causing hydraulic fluid to be sprayed on the hot engine exhaust, starting a fire. Fire was extinguished with the aircraft's fire extinguisher."[19]

"UH-1B—Pilot attempted to bring the helicopter to a hover. The left skid (upslope) lifted off the ground first to a height of three feet. The right skid remained in ground contact until the aircraft rolled over. Upon rolling over, the transmission separated from the aircraft, dumping hydraulic fluid (MIL-H-5606), and lubricating oil (MIL-L-7808) into gear teeth which were emitting sparks."[20]

Investigators of this accident believed that the hydraulic fluid, because of its low flash point, ignited first, then ignited the lubricating oil.

Fortunately, through quick use of hand extinguishers, these fires did not develop to any size.

DOLLAR COST: The effect of the new and more expensive models recently added to the helicopter inventory is seen in the cost of the 55 fire accidents during the two year period FY 64-65. The dollar cost of helicopters damaged in fire accidents during the six previous years was approximately 12 million dollars. The total, as of FY 65, reached 20 million dollars. More than half of the eight million dollar increase is attributable to 18 UH-1 and two CH-47 fire accidents.

From the available information concerning these accidents, one cannot say with certainty how much of the cost is due to fire alone. It is, however, possible to make a reasonable estimate by comparing the cost of fire and nonfire accidents. The experience of the OH-13G and H is used for this comparison. Five of its 40 roll-over accidents were followed by post-crash fires. All five of these helicopters were totally destroyed, compared to only 10 destroyed of the 35 accidents without fire. The cost of nonfire accidents averaged $26,000, 65% of the OH-13 cost. A like cost difference was found in the more damaging accidents typed as "main rotor struck the ground." These comparisons indicate that these post-crash fires add at least 35% to accident costs. This addition strongly suggests that dollars spent for crash-fire-worthiness will return a significant savings.

FIRE BY ACCIDENT TYPE: Fires in helicopter accidents, particularly post-crash fires, are not confined to one accident type. The fire accidents listed in Table 4 are scattered among 21 different types, but tend to concentrate in six types. These six headed by "Collision in air—with trees," with a total of 18, is closely followed by "Controlled" and "Uncontrolled" collision with terrain, each with a frequency of 17. The incidence of fire increases as the severity of impact increases. This is apparent in the frequency in which fire appears in collision accidents. These collision accident types not only produced 35% of the fire accidents, but also account for almost half (47%) of the nonsurvivable fire accidents, a further indication of their severity.

Classifying accidents into the types listed in Table 4 is a subjective procedure used to aid analysis. Type classification is accomplished on the basis of accident descriptions provided by investigators. The following description of an OH-23F post-crash fire accident, classified as a roll-over accident, is typical of the information received:

"The engine quit, the pilot autorotated straight ahead into the wind, with a full flare and very little forward motion at touchdown. On touchdown, the helicopter rolled to the right and the blades contacted the ground. Blade momentum was very low. Each contacted the ground once before stopping. The helicopter came to rest inverted. Almost immediately after ground contact, the helicopter began to burn. The fire immediately engulfed the helicopter . . ."[21]

The above accident is typical of the sequence of roll-over accidents. In many of this type, the crash forces do not break the plexiglass bubble cockpit enclosure, but for various reasons, result in fuel spillage. Fire, as Table 4 shows, was present in three of 16 OH-23 roll-overs and five of 40 OH-13G and H roll-overs. No fire followed 33 OH-13D and E roll-over accidents. The UH-1A and B had fire in two of eight roll-over accidents.

The following comments, made by the investigator of a UH-1A roll-over accident, resulted in the modification of its fuel vent system to prevent recurrence:

"Fuel spillage in this accident was the result of the attitude of the aircraft, not the rather severe impact condition. If the aircraft had rolled on its right side, a fire would probably not have occurred because of the location of the fuel vent terminal."[22]

Roll-over, a characteristic event in the helicopter accident sequence, is usually the terminal event. This final position must be considered in the crash-fire-worthiness design. The above accident is a case in point. The stub type wings that appear to be forthcoming on the next generation of helicopters, as in fixed wing aircraft, are expected to add needed stability.

TABLE 4

Fire Occurrence by Type of Major Accident and Model
July 1957 - June 1965

TYPES OF ACCIDENTS	OH-23		OH-13G,H		OH-13D,E		OH-13S		CH-34		CH-21		UH-19		UH-1A,B		UH-1D		CH-47		CH-37		TOTAL	
	S	NS	S	NS	S	NS	S	NS	S	NS	S	NS	S	NS	S	NS	S	NS	S	NS	S	NS	S	NS
Roll Over	3	0	5	0	0	0	0	0	1	0	1	0	0	0	2	0	0	0	0	0	0	0	12	0
Collision with terrain-Controlled	0	1	2	1	0	0	0	0	4	1	1	2	2	1	1	0	0	0	0	0	0	1	10	7
Collision with terrain-Uncontrolled	1	2	2	1	1	0	0	0	2	0	1	5	0	0	2	0	0	0	0	0	0	0	9	8
Collision in air, trees, etc.	0	0	2	1	1	0	1	0	3	2	1	0	1	0	1	2	3	0	0	0	0	0	13	5
Collision in air, aircraft	0	2	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	2	0	0	0	0	0	5
Collision on terrain, bldgs, ditches	0	0	1	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	3	0
Collision on terrain-other	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
Fire-before accident occurred	0	0	1	0	0	0	0	0	1	0	0	0	1	1	0	2	0	0	1	0	0	0	4	3
Fire-during ground operations	0	0	1	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	3	0
Wire strike	4	1	3	2	2	0	0	0	0	0	1	0	1	0	1	0	0	0	1	0	0	0	13	3
Tail rotor striking landing area	2	0	3	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	0
Main rotor hits terrain	0	0	5	0	2	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	8	0
Rotor blades hit part of aircraft	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	2
Spin/stall-landing or takeoff	1	0	0	0	0	0	0	0	0	1	0	0	1	0	1	0	0	0	0	0	0	0	3	1
Spin/stall-inverted	0	0	0	2	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	3
Spin/stall-clean configuration	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Spin/stall-settling with power	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0
Hard landing	1	0	3	0	0	0	0	0	2	0	1	0	1	0	2	1	1	0	0	0	0	0	11	1
Under shoot runway	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0
Under shoot other landing area	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0
Airframe failure inflight/on ground	0	1	0	0	0	0	0	0	0	0	1	0	0	1	0	1	0	0	0	0	1	0	2	3
Other	1	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0

TABLE 5

Location of Helicopter Fire Accidents
July 1957 - June 1965

FY PERIOD	WITHIN USA	OUTSIDE USA	ON POST		OFF POST	
			ON AIRFIELD	OFF AIRFIELD	ON AIRFIELD	OFF AIRFIELD
1965	19	12	5	4	0	22
1964	19	5	4	7	1	12
1963	13	9	2	6	1	13
1962	10	12	7	4	2	9
1961	3	3	0	3	0	3
1960	10	4	3	6	0	5
1959	11	2	1	5	0	7
1958	10	5	3	5	0	7
TOTAL	95	52	25	40	4	78
ANNUAL MEAN	11.9	6.5	3.1	5.0	.5	9.8
PERCENT	65	35	17	27	2.7	53

Wire strike accidents, always a hazard to the low level flight which is characteristic of helicopter operations, produced post-crash fires in 16 of 115 major accidents of this type. Observation helicopters were involved more frequently. OH-23 and OH-13 aircraft accounted for 89 (77%) of 115 wire strike accidents. These two models, as shown in Table 4, produced 12 of the 16 wire strike fire accidents.

WHERE FIRE ACCIDENTS OCCUR: The distance from crash-rescue services is a critical factor in fire accidents. Rescue of victims of a fire accident must take place almost immediately to insure survival. The Army's problem in this respect is quite clear in data of Table 5. The data show that only 29 fire accidents, less than four accidents per year, occurred on airfields, where crash-rescue equipment was readily available. More than half (56%) of the fire accidents were outside the bounds of Army posts. There are no indications that this picture will change in the future. For example, during FY 58, 12 of 15 were not on airfields. In FY 65, the ratio remained approximately the same, when 26 of the 31 fire accidents were away from airfields.

It would have been helpful if this report could relate key details of crash rescue, such as sequence of rescue events, distance to the crash site, difficulties encountered attempting to reach the crash site, and the effectiveness of equipment and techniques employed. These are seldom reported, since the crash rescue phase of accident investigations has not been emphasized in the past. It is hoped that future reports will supply these needed details.

The helicopter, because of its speed and maneuverability, is considered the most suitable vehicle for crash rescue of off-station sites. Table 6 indicates that each fire accident involves at least three people on the average, two of whom will be injured to some degree. More than half (54%) of the injured have thermal injuries.

This report does not include Vietnam accidents, where the number of personnel aboard during airlift operations is always near capacity. The UH-1D normally carries nine troops, plus a crew of four. This number is more than doubled when the Chinook (CH-47) is loaded to its capacity. The requirement for highly responsive and effective crash-fire-rescue is increasing. When the CH-54 "Skycrane" personnel pod is placed into use, the number aboard the aircraft will total 58, including the crew. This problem demands immediate attention of the kind now devoted to the helicopter fuel systems.

The following selected briefs, dealing with small observation helicopters point out the magnitude of this problem. It is not unlike the one facing civil aviation, as commercial airliners steadily increase their passenger capacity.

"The fire department arrived, extinguished the fire, but the helicopter was a total loss . . ." ". . . area of the fire was inaccessible to the crash fire fighting equipment . . ."[23] This accident on an Army airfield was less than a mile from stationed crash truck.

". . . I heard the crash. By the time I got there the crew was out. I would say from my office to the burning wreckage was less than one minute. By that time, the flames were such I could not have been any help had they needed it . . . large flames rose almost immediately. It was almost 10 minutes before the airport fire department started to extinguish the flames . . ."[24] This fire occurred just 60 feet off a taxiway of a major municipal airport.

Another case involved a UH-1D which, fortunately, after crashing through trees, did not roll over to hinder the escape of seven fully equipped troops and its crew of three. This accident occurred during assault lift training. It illustrates the response time of the crash rescue service and the concerted effort

TABLE 6

Helicopter Fire Accidents Occupant Experience by Location
July 1957 - June 1965

NUMBER OF PERSONNEL	TOTAL	WITHIN USA	OUTSIDE USA	ON POST		OFF POST	
				ON AIRFIELD	OFF AIRFIELD	ON AIRFIELD	OFF AIRFIELD
INVOLVED	452	294	158	65	102	17	268
INJURED	297	194	103	37	74	1	185
FATAL	161	123	38	13	43	0	105
THERMAL INJURED	159	110	49	17	42	1	99
FATALITIES DUE TO BURNS	35	27	13	0	9	0	26

made by an assault unit to deal with the problem.

"Personnel exited the aircraft from both sides. . . . at this time there was fire in the engine area. The medical evacuation helicopter arrived within 5 to 8 minutes and all were taken to the hospital. The airborne fighting equipment (FSN 4210-672-8209, Mfg Kaman Aircraft Corp.) arrived in approximately five minutes but could not control the fire. Fire trucks arrived and extinguished the remaining fire."[17]

This report reflects current practices of crash-fire rescue and shows that little can be done to prevent destruction of helicopters in fire accidents. As indicated in the above briefs, when the main fuel system is involved, the fire is intense and spreads rapidly. Another factor is the fact that these fires occur predominantly at locations away from stationed fire crash-rescue equipment. Of 106 fire impact survivable accidents in which the damage should have been relatively light, more than two-thirds of the helicopters were totally destroyed. In the discussion of cost, it was shown that fire accounts for a part of this loss. Thirty of 33 OH-13G and H models were written off as total losses as were nine of 13 OH-23's involved in survivable fire accidents. Nine CH-34 helicopters involved in 21 fire accidents were totally destroyed.

COMPARISON OF OCCUPANT INJURY EXPERIENCE: The data of this report have dealt primarily with the materiel and operational aspects of the fire problem. Emphasis in these areas must remain strong until the recent advances noted in the technology of flammable fluid containment becomes a reality. It is well to observe that those grappling with the problem are tempering their efforts by recognizing the operational use the Army makes of helicopters.

As these requirements are met, an improvement in occupant injury portion of the fire problem should occur. This change will not be abrupt or obvious. Improvements in the injury and fatality ratio are expected to be gradual, unless past delays in the use of modifications are avoided. Otherwise, a number of helicopters in the inventory today will continue to contribute to the fire accident picture at the ratios indicated in Table 9.

Part of that picture expected to remain is presented in Tables 8 and 9. Fire accidents now account for 10% of the major accidents and are responsible for 44% of the injured and 72% of the fatalities in all major helicopter accidents.

Of 677 injured, 159 (24%) suffered burns of some degree. Survivable fire accidents accounted for 10% of 224 fatalities in 1,425 major accidents included in this report. Eighteen (45%) of these fatalities were due to fatal thermal injuries.

The added hazard of fire and the kinds of acci-

TABLE 7

Major Helicopter Accidents Occupant Injury Experience Excluding Fire
July 1957 - June 1965

NUMBER	TOTAL	FY 58-61	FY 62-63	FY 64-65	CHANGE FY 62-63 VS 64-65 NO	PERCENT
MAJOR ACCIDENTS	1278	664	348	266	-82	-24
OCCUPANTS INVOLVED	3593	1804	944	845	-99	-10
INJURED	380	115	106	159	53	50
FATALLY INJURED	63	28	15	20	5	33
PERCENT INJURED	11	64	12	19		
PERCENT SURVIVED	98	98	98	98		

TABLE 8

Helicopter Fire Accidents Occupant Injury Experience
July 1957 - June 1965

NUMBER OF OCCUPANTS	TOTAL	FY 58-61	FY 62-63	FY 64-65	CHANGE FY 62-63 VS 64-65 NO	PERCENT
INVOLVED	452	142	113	197	84	74
INJURED	297	92	82	123	41	50
FATALLY INJURED	161	49	51	61	10	20
INJURED THERMAL	159	60	47	52	5	11
FATAL THERMAL	35	14	13	8	-5	-38
PERCENT INJURED	66	65	73	62		
PERCENT SURVIVED	64	65	55	69		
PERCENT WITH BURNS	35	42	42	26		

dents that produce post-crash fires are apparent upon comparing the occupant survival rate of the fire and nonfire accidents of Tables 7 and 8. They show 98% of the nonfire occupants survive, compared to 64% of the fire accidents.

Though the thermal injuries and fatalities are given in these tables, the role thermal injuries play in the fire accident survival rate is greater than that indicated by the 35 thermal fatalities. The thermal injury role can be assumed to be greater by a significant factor in light of the fact that two of the 161 fire accident fatalities had no burns. However, to what degree burn complications contributed to death in these cases is not known. It should be made clear that, of the 35 thermal fatalities, the cause of death was determined on the basis of autopsy findings in 31 cases. In 17% of the cases, tissue specimens were forwarded to the Armed Forces Institute of Pathology.

The survival rate in fire accidents is lower because these accidents are generally more severe from a standpoint of impact forces. The record shows that 95% of all major helicopter accidents, including fire accidents, are survivable. Data of this report show fire accidents to be more severe. During the FY 58-63 period, 70% of the fire accidents were survivable. This percentage, as of FY 65, has now increased to 72% for the 147 fire accidents included in this report.

It is clear from the tables and statements in this report that the occupant injury picture was not expected to show any definite signs of improving during FY 64-65. The FY 64-65 fire accident picture shows an increase in the overall injury and fatality rate per accident and a decrease in the thermal injury and fatality rate. The rates per fire accident for FY 58-63 were: injured 1.89, fatal 1.09, injured thermal 1.16, and fatal thermal 0.29. During FY 64-65, these rates per fire accident were: injured 2.24, fatal 1.22, injured thermal .94, and fatal thermal .15.

A part of the increase in the injury picture is explained by the steady increase in the number of occupants involved in each of these fire accidents. During the period FY 58-63, the number of occupants per accident was 2.8. This increased to 3.6 during FY 64-65. To compare FY 58-61, the beginning of the period, to FY 64-65, the number of occupants per fire accident shows an even greater increase. It averaged 1.8 occupants per accident at that time. This steady increase in the number of occupants exposed to the hazards of fire accidents is another strong plea for improving the helicopter's crash-fire-worthiness.

An intensive crash-fire-worthiness improvement effort which would essentially eliminate the fire hazard can, in theory, approach the injury rates of nonfire accidents. These accidents, like the fire accidents, show an increase in the injury and fatality rate per accident. For FY 58-61, the injury rate was 0.17, the fatality rate was 0.04. The injury rate climbed to 0.60 and the fatality rate doubled to 0.08 during FY 64-65. These rates which are significantly lower than the fire accident rates illustrate the severity of the crash forces of fire accidents, plus the added hazard of fire.

The injuries referenced in this report are, in almost all cases, classified by attending flight surgeons who served as members of the accident investigation boards. Four injury classifications, defined as follows, are reflected in the injury data.

Minor: Injury from which recovery is expected and which is considered (for reporting and coding) an injury less than major.

Major: Injury less than critical, recovery expected, requiring more than five days hospitalization and/or quarters.

Critical: Injuries which threaten to result in death, either from injuries sustained in the accident, or from complications.

Fatal: Any injury which results in death prior to submission of Flight Surgeons Technical Report of Aircraft Accident.

TABLE 9

Occupant Injury Experience in Fire Accidents by Helicopter Model
July 1957 - June 1965

AIRCRAFT	NO. OF ACDTS		NUMBER OF OCCUPANTS: INVOLVED		INJURED		FATALITIES		PERCENT INJURED		PERCENT SURVIVED		INJURED THERMAL		THERMAL FATALITIES	
	S	NS	S	NS	S	NS	S	NS	S	NS	S	NS	S	NS	S	NS
OH-23	13	7	23	13	20	13	4	13	87	100	83	0.0	4	10	2	0
OH-13G,H,K	33	9	50	13	33	13	4	11	66	100	92	15	20	12	3	1
OH-13D,E	6	0	10	0	7	0	1	0	70		90		2	0	0	0
OH-13S,T	2	0	4	0	2	0	0	0	50		100		0	0	0	0
CH-34	16	5	72	14	44	14	10	14	61	100	86	0.0	25	12	9	9
CH-21	9	9	33	43	13	40	2	38	39	93	94	12	1	22	0	4
UH-19	8	2	26	6	5	6	1	6	19	100	96	0.0	3	6	1	0
UH-1A,B	11	6	48	19	29	19	10	19	60	100	79	0.0	10	17	3	0
UH-1D	5	2	35	18	5	18	0	18	14	100	100	0.0	0	5	0	0
CH-47	2	0	7	0	2	0	1	0	29	0.0	86		1	0	0	0
CH-37	1	2	9	9	5	9	0	9	56	100	100	0.0	1	8	0	3
PERCENT SURVIVABLE	72		70		56		20						42		52	

The injuries of 297 injured fire-accident occupants were: 22% minor, 23% major, 1.7% critical, and 53% fatal.

OCCUPANT EXPERIENCE BY MODEL OF HELICOPTER: How much protection did each model provide its occupants in the 106 survivable and 41 nonsurvivable fire accidents of this study? The answer to a portion of this question can be found in the injury and fatality data of Table 9.

The portion of the above question that remains unanswered is the condition under which these accidents and injuries took place. Such details can be learned by thoroughly reviewing each accident report. Survivor statements and findings of the investigators included in these reports often explain why only one of two people in an accident is injured, or why the thermal injuries of one are so much more severe than the other. The statements made by two occupants of an OH-13H fire accident that followed a hard landing illustrate this point. The crewchief escaped without injury after the burning helicopter had come to rest on its right side.

The crewchief stated: "When the aircraft stopped, he (the pilot) unbuckled his seat belt and asked if I were getting out. I replied yes. At the same time, he fell in front of me and went out the right front of the bubble which had shattered. The fire was pretty heavy in that area. I unbuckled my harness while he was getting out and then went out the pilot's door."[24]

The pilot in this accident received burns of the face, hands, knees, and ankles. His statement describes how these were received, his concern for his crewchief, and how the wind, gusting to 26 knots, kept the crewchief free of the flames to escape injury.

The pilot stated: "I released the safety belt with my left hand. And as I released it, I fell down on the fire and I just kept going. I looked about for the crewchief. I went back to the aircraft but this time I came from the side opposite the fire. The way the aircraft was laying the wind was from left to right."[24]

Data shown in Table 9, as well as that shown in Table 3, are evidence of the protective location of the OH-23 fuel tanks. Table 9 data indicate that fire erupts less frequently in OH-23 major accidents. The OH-23 ratio of fire to major accidents is one in fourteen, compared to one in eight for the OH-13G and H. Greater crash forces, necessary to spill fuel from the OH-23 system, are also apparent in the percentage of fire accidents which are nonsurvivable. Thirty-five percent of its fire accidents are that severe. Only the CH-21, at 50%, exceeds this figure. Whether by coincidence or because their fuel cells are in the same relative location, the UH-1's equal the OH-23 figure. Fire apparently erupts much easier in the OH-13G and H, since 21% of its accidents are nonsurvivable.

There is also an indication in the injury data of survivable accidents that greater crash forces are attained by those models that give the most protection to its fuel tanks. Again, the OH-23 and UH-1 can be cited. For example, many more OH-23 occupants in these accidents are injured. Table 9 shows 87% are injured. Significant to this point is the fact that only four of the 20 injured received thermal injuries. The other 16 occupants were injured by crash forces. The record shows that the four occupants with burns also received other injuries. The two thermal fatalities occurred because other injuries prevented escape from the burning wreckage.

Fuel tank location and provisions for emergency escape are the two main factors that determine the thermal injury experience of the aircraft listed in Table 9. The fire accidents of the two observation models, since they are essentially of the same configuration, structural design, and dimensions, explain the first factor. The escape factors in these aircraft are identical, since both have a bubble-like plexiglass cockpit enclosure that easily breaks upon impact. The locations of their occupants to the main bulk of the fire, however, are not the same because the locations of their fuel tanks differ. The occupants of the OH-23 are separated from the main fire by the floor and the aft wall of the cockpit. The accident reports of this aircraft show that fire, even in the case of roll-over, tends to stay behind the occupants for a long enough time to allow for their escape. The location of the OH-13G and H tanks, aft and above the cockpit, permits fire to spread down into the cockpit faster. The following statement from a flight surgeon's report describes how the flames enter the OH-13 cockpit:

"When the aircraft fell over, the bubble broke and the right tank ruptured releasing fuel which ignited on the hot manifold. It then spilled into the cockpit seating area. The spray of burning fuel on the pilot's face, hands, and clothes continued to burn as he exited through the shattered plexiglass . . ."[25]

Because this fire pattern is often repeated, the OH-13G and H are second only to the larger CH-34 in the number of burned occupants. The OH-13, a two-place model, is responsible for 30% of the thermally injured occupants in survivable accidents. The chance of thermal injury in the OH-13G and H (see Table 9) is greater than all other models. Forty percent of its occupants receive burns, compared to 35% for the CH-34, the next highest.

The CH-34, in four post-crash fires during FY 64-65, added 18 thermally injured occupants and six thermal fatalities to its survivable fire accident record. One of the accidents[12] illustrates what happens when passenger capacity increases and provisions for escape are inadequate. This one accident accounted for 13 of the 18 thermally injured during this period. The accident happened when the pilot was unable to reach a suitable touchdown area after the engine had failed. All 13 aboard suffered burns and five received fatal burns. The five fatalities of this one accident are equal to half of the thermal fatalities recorded in the survivable accidents of all models during the previous six years. The fatalities occurred because the only cabin door was blocked. Typically, in other CH-34 and UH-19 fire accidents, a wall of flame hindered passage through the cockpit to the exit windows. The crew and other survivors were saved after witnesses to the accident battered their way through a cockpit window.

Also among these models, the record of the CH-21 in survivable accidents stands out, particularly in regard to thermal injury. Only one occupant suffered thermal injury, even though its fire-accident experience was equal or greater, and involved more occupants than other models. Undoubtedly, much of its record is due to the availability of escape exits. Its cargo compartment, unlike the UH-19 and CH-34, has convenient openings on both sides, including the large cargo door on the right.

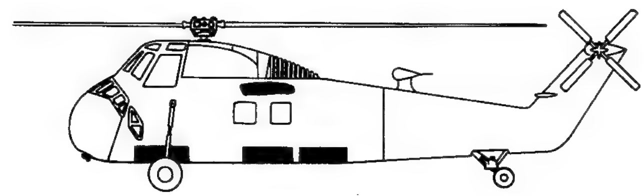


FIGURE 6

CH-34 With Three Fuel Cells in the Belly of the Helicopter

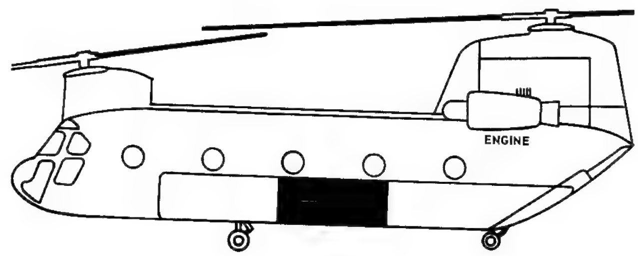


FIGURE 7

CH-47 Fuel Cells Remote From Engine Area

The survival of seven occupants in nonsurvivable accidents of the OH-13G and H, and CH-21 is an example of the ineptness of the definition of accident survivability to meet the variety of conditions accidents present. The CH-21 was involved in two accidents of this type. In each case, the sequence of impact was quite similar. The crew compartment impacted first and sustained sufficient damage to cause the accident to be classified as nonsurvivable. The collapsing structure of the crew compartment reduced the forces transmitted to the cargo compartment, thus permitting this area to be survivable. In one accident, a passenger was thrown clear of the wreckage into the snow and escaped with only minor injuries. He was able to rescue a more seriously injured passenger from the fire that caused the death of four others.

The low injury percentage and 100% survivability the UH-1D achieved in five survivable fire accidents resulted because crash forces were not great enough to involve the main fuel tanks in fire before the occupants could escape. Injury occurred in only two of the five accidents. The tanks did not leak fuel in either accident involving injury. However, in one accident, the use of portable fire extinguishers stopped the hydraulic fluid fire from reaching spilled JP-4 fuel. The other UH-1D crashed through trees

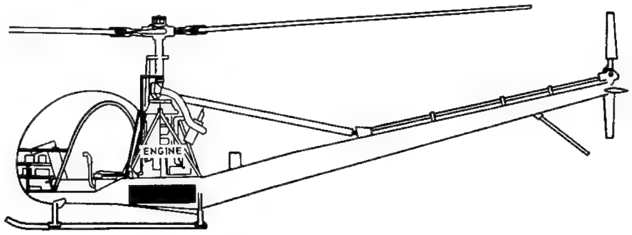


FIGURE 8

OH-23 Single Bladder-Type Fuel Cell

just after taking off from a tactical unit helipad. This accident[18] injured three of the occupants, two sustaining minor injuries and one sustaining major injuries. None received thermal injuries. The pilot was unable to get out of the wreckage because of major injury to his spine, and was rescued by the crewchief and another survivor. They freed the pilot only seconds before the engine fire spread to the main fuel tanks.

A mid-air collision, followed by fire upon impact, accounts for the 100% injury rate and zero survivability of the two UH-1D nonsurvivable fire accidents of this period. Five of the 18 fatalities of this collision were burned, but in no case did the pathologist cite thermal injuries as the cause of death.

The UH-1A and B during FY 64-65 added seven survivable and four nonsurvivable fire accidents to its earlier record. Seventeen of the 28 occupants involved in the survivable accidents were injured. Only four, all in one accident,[26] received thermal injuries. These injuries, which included a thermal fatality, were caused by burning fuel from an auxiliary tank that ruptured upon impact. The tank, as designed, was secured to the floor aft of the crew seats of the UH-1B. The investigating board of this accident recommended auxiliary tanks of increased crash resistant strength be developed. Tanks made of "Tough Wall" will be able to fulfill that recommendation.

Only one other UH-1B survivable accident,[27] which accounts for the other fatality of this period, was severe enough to rupture the fuel cells. Neither of the two occupants was burned. The survivor of this accident, seated away from the aircraft's main point of impact, received only minor injuries because his seat broke loose, allowing him to be thrown free of the wreckage.

THERMAL INJURY: *"Before I went through the flames, I consciously held my breath. I would estimate my total time of exposure to the intense heat was three to five seconds."*[28]

A variety of burn injuries have been experienced by occupants of helicopter fire accidents. The pilot who made the above statement, by holding his breath, saved himself from burn injuries to his respiratory system. However, as this statement from the attending flight surgeon shows, that same pilot did not follow equally effective practices in regard to wearing protective clothing. The protective value of flight gloves and boots is well documented by this accident.

"The aircraft was burning fiercely on impact; the bubble (which fortunately remained intact) was completely enveloped in flames. The student pilot had already received burns to the right side of his neck (he was wearing an APH-5), when the right door blew open momentarily before the ship rolled to a rest on that side. The instructor pilot opened the upper door and was blinded by the flames. To exit he had to grasp the door frame with his ungloved hand. He knew the hot metal and direct flame was

TABLE 10

Occupant Thermal Injury by Body Area and Degree
July 1957 - June 1965

BODY AREA	SURVIVABLE ACCIDENTS PERCENT OF INJURIES	SURVIVABLE ACCIDENTS DEGREE OF BURN 1 & 2°	SURVIVABLE ACCIDENTS DEGREE OF BURN 3° & UP	NON-SURVIVABLE ACCIDENTS PERCENT OF INJURIES	NON-SURVIVABLE ACCIDENTS DEGREE OF BURN 1 & 2°	NON-SURVIVABLE ACCIDENTS DEGREE OF BURN 3° & UP
HEAD	5.0	57	43	3.0	50	50
FACE	19.0	63	37	0.0	0	0
NECK	5.0	70	30	0.0	0	0
UPPER EXTREMITIES	26.0	56	44	9.0	20	80
CHEST	1.0	0	100	4.5	66	33
ABDOMEN	0.0	0	0	0.0	0	0
PELVIS	0.0	0	0	0.0	0	0
BACK	.7	100	0	4.5	33	66
LEGS	14.0	40	60	9.0	10	90
GENERAL	29.0	18	82	71.0	0	100
NO. OF OCCUPANTS	67 INJURED - 18 FATAL			92 INJURED - 17 FATAL		

burning his hand, but he had no choice. His clothes (K-2B flight suit) caught fire as he escaped over the base of the aircraft to the ground. The student pilot followed through the same door a few seconds later when the metal and flames were even hotter. He was wearing gloves, however. After his hurried exit, he pulled off his burned and smoking gloves which he thought were on fire, but found that his hands were completely free of burns or any other injury. In addition, the instructor pilot was wearing ***low quarter*** *shoes and his* ***synthetic cloth stockings*** *burned at the exposed area, with attendant burns to both ankles. The student was wearing* ***combat boots*** *and had no injury of this type."*[28]

The helmet effectively reduces burn injuries to the head. Its effectiveness is proven in the data of Table 10, by comparing the percentage of burn injuries to the head and neck against those of the face. The face received 19% of the burn injuries of survivable accidents. That figure is almost four times the 5% received at the head and neck. The burn injuries to the head were sustained mainly by 88 occupants who did not wear helmets or whose helmets were dislodged and came off during the crash. Thirteen (38%) of those who lost their helmets received burns to the head, and twelve (14%) of the 88 who did wear the helmet had head burns.

Removing the helmet prior to exit in these crashes had also contributed to thermal head injuries of Table 10. Why the helmet is removed is a reaction that is not clearly understood. One pilot, questioned on this point, said, "I released my seat belt and for some reason, thinking that the helmet would keep me in the helicopter, I removed it also."[29] Another, who had the presence of mind to hold his breath while exiting, removed his helmet. The only burns he suffered were to his head and neck. Still another pilot,[12] trapped with his copilot in the cockpit of a CH-34, said he removed his helmet to talk. He suffered second degree burns to his face during escape.

A number of other accidents like the one referring to the instructor pilot and student pilot attest to the protection given by gloves and how well they serve the wearer during escape. Despite their known protective value, aviators must constantly be urged to wear them. The records show that, of the 149 aviators involved in the survivable fire accidents, only 55 (37%) reportedly wore gloves. The record also shows that 22 of them who did not wear gloves suffered burns to their hands. One of the main reasons in the past why aviators did not wear the gloves was that they were bulky and required an insert which essentially eliminated the sense of touch needed by pilots. Further, the early issue gloves did not have a gauntlet to protect the wrist. The B-3A glove, a gauntlet type of soft leather which does not require an insert, is now being issued to aviators. Tests of a gauntlet glove made of a cabretta leather on the palm and high temperature (NOMEX) nylon on the top are being conducted. Favorable test results indicate this glove will be adopted for use.

The K-2B flight suits worn by the instructor pilot and his student in the cited accident are not fire resistant unless chemically treated. An intensive campaign has been conducted at USABAAR to chemically treat flight suits with a water mixture consisting of borax, boric acid, and diammonium phosphate. Reportedly, many units and individual aviators have picked up the practice. How many of the 149 aviators and 39 crewchiefs of the survivable fire accidents had treated their flight suits or fatigues is not known. The record shows that only 37 (26%) of the aviators wore flight suits of any model. Recent action to develop a flight suit made of a high temperature nylon with the trade name NOMEX is expected to give Army aviators much of the needed protection. This material is fire resistant and will not sustain a flame until 740°F is reached. That temperature, depending upon the length of exposure, of course, is in the range of fatal burns. Other materials, capable of sustaining high temperatures, perhaps more suitable than NOMEX, are under development.

The thermal injuries of Table 10 show skin injuries by body area, and the degree of thermal injury to that area. These injuries, given in percentages, show that, in survivable accidents, the arms (upper extremity) at 26%, face at 19%, and legs at 14% are in need of protection. The 29% indicated for general body area, as the degree of their burns show, were sustained by the 18 thermal fatalities of this accident category. The value of emphasizing the use of protective clothing is clear in these data. The one body area that remains unprotected is the face. Protection is available to those whose helmets are to be retrofitted with visors made of polycarbonate resin material. This visor, which resists shatter and penetration of fragments, is a recent development to be made available in limited quantity for aviators in Vietnam. This visor, unlike those made of acrylic, will not support combustion. Furthermore, the reported cost of the acrylic visor is approximately $4.00 each, compared to $1.75 for the polycarbon visor. The minor optical deficiencies of the polycarbon visors are not considered serious enough to restrict its general use. The visors made of this material, worn in the lowered position, will protect against many of the disfiguring burns now received to the upper part of the face.

In reported cases of respiratory system injuries, escape was hindered in some manner. In one case, a crewchief panicked at the sight of flames. He forgot about the quick release of his shoulder harness and lap belt. He struggled until he managed finally to slip beneath the belt. In another, a pilot fought the release of his lap belt (he had learned

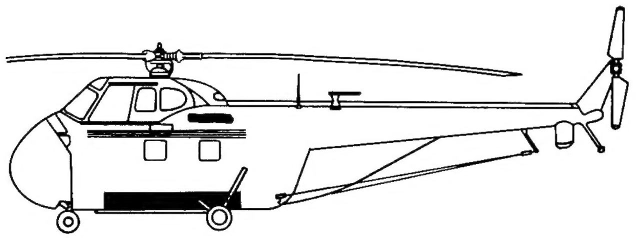


FIGURE 9

UH-19 Fuel Cell Location in Relation to Landing Gear and Engine Area

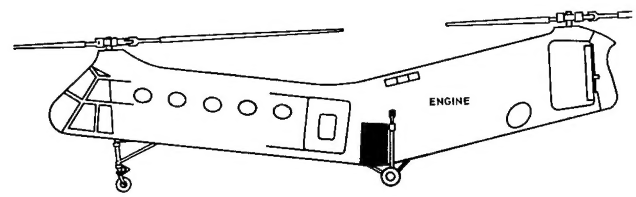


FIGURE 10

CH-21 in Relation to Landing Gear Fuel Cell Location and Engine Area

during preflight inspection that it was improperly installed in the aircraft and would require the reverse of the normal procedure to release it). Still another passenger, upon exiting through the emergency hatch of a CH-34 into the heat of the flames said, "I could feel the heat. It hit me full in the face, and when I caught my breath, I breathed in those fumes."[12] He suffered no major injury as a result. Others were not so fortunate. In two cases, occupants suffered blows to their heads, and in an unconscious state, inhaled superheated air from flash fires that swept through the cockpits. One of them wore a helmet, but a blow on the forehead was thought to have caused loss of consciousness. The other did not use his helmet. He placed it in the seat next to him because the flight was to be "just a short hop."

The thermal injuries of Table 10 represent the injuries sustained by the 159 thermally injured occupants of this report. It also includes the thermal injuries that were fatal to 35 occupants. The fatal injuries were usually those (Table 10) that covered the general body area and were described as third degree, or more severe. The 18 thermal fatalities of the survivable accidents included five aviators and five crewchiefs. Causes of death in 17 of these cases were determined on the basis of autopsy findings. Autopsy findings established causes of death for 14 of the 17 nonsurvivable thermal fatalities. Even in the cases with the evidence found during autopsy, causes of death cannot always be established without qualification. Qualifications are usually of this nature when the carboxyhemoglobin is found to be within normal limits.

"This subject was rendered unconscious at the time of impact and expired from the effects of the fire that ensued. The advanced degree of incineration precludes definite opinion as to the nature of the injury that caused the subject to lose consciousness, but it was most likely a blow on the head. It would be difficult to prove that the subject died of thermal injury as sections of the trachea are not available and the carboxyhemoglobin is within normal limits. The lung histology is compatible with death by fire. It is possible that the head trauma was of sufficient severity to cause death, however. The gross distortion of the brain by the effects of the fire prevent a definite opinion on this point. In helicopter accidents of this type, the occupants of the rear section of the aircraft tend to have the more severe injuries due to the collapse of the major engine parts into that section. No pre-existing disease was found."[30]

REFERENCES

1. Spezia, E., "U. S. Army Helicopter Accidents Involving Fire," Report No. 1-64, Human Factors Section, USABAAR, Fort Rucker, Alabama.
2. Robertson, H. S., Turnbow, J. W., "Aircraft Fuel Tank Design Criteria," Report No. 66-24, U. S. Army Aviation Materiel Laboratories, Fort Eustis, Virginia.
3. Forced Landing, File No. 2244, 4 May 1960, UH-19D, USABAAR, Fort Rucker, Alabama.
4. Forced Landing, File No. 5329, 27 October 1962, CH-34A, USABAAR, Fort Rucker, Alabama.
5. Forced Landing, File No. 3766, 18 August 1961, CH-37B, USABAAR, Fort Rucker, Alabama.
6. Precautionary Landing, File No. A515, 17 September 1964, OH-13S, USABAAR, Fort Rucker, Alabama.
7. Aircraft Accident, File No. 03783, 23 August 1961, OH-13G, USABAAR, Fort Rucker, Alabama.

8. Aircraft Accident, File No. 02576, 15 July 1960, OH-13H, USABAAR, Fort Rucker, Alabama.
9. Aircraft Accident, File No. 8308, 19 May 1964, USABAAR, Fort Rucker, Alabama.
10. Aircraft Accident, File No. B896, 21 May 1965, UH-1D, USABAAR, Fort Rucker, Alabama.
11. Aircraft Accident, File No. 0434, 21 March 1958, UH-19C, USABAAR, Fort Rucker, Alabama.
12. Aircraft Accident, File No. 7313, 2 December 1963, CH-34C, USABAAR, Fort Rucker, Alabama.
13. Aircraft Accident, File No. B544, 4 March 1965, CH-47A, USABAAR, Fort Rucker, Alabama.
14. Aircraft Accident, File No. A382, 30 August 1964, UH-1B, USABAAR, Fort Rucker, Alabama.
15. Incident, File No. 7589, 30 January 1964, UH-1A, USABAAR, Fort Rucker, Alabama.
16. Forced Landing, File No. 2816, 29 September 1960, UH-19D, USABAAR, Fort Rucker, Alabama.
17. Aircraft Accident, File No. 7089, 8 August 1963, UH-1B, USABAAR, Fort Rucker, Alabama.
18. Aircraft Accident, File No. B376, 9 September 1965, UH-1D, USABAAR, Fort Rucker, Alabama.
19. Aircraft Accident, File No. 8401, 4 June 1964, UH-19D, USABAAR, Fort Rucker, Alabama.
20. Aircraft Accident, File No. C545, 3 March 1965, UH-1B, USABAAR, Fort Rucker, Alabama.
21. Aircraft Accident, File No. C892, 24 September 1965, OH-23F, USABAAR, Fort Rucker, Alabama.
22. Aircraft Accident, File No. 6903, 11 September 1964, UH-1A, USABAAR, Fort Rucker, Alabama.
23. Aircraft Accident, File No. 01505, 13 June 1959, OH-13G, USABAAR, Fort Rucker, Alabama.
24. Aircraft Accident, File No. 07919, 24 March 1964, OH-13G, USABAAR, Fort Rucker, Alabama.
25. Aircraft Accident, File No. 04679, 21 May 1962, OH-13H, USABAAR, Fort Rucker, Alabama.
26. Aircraft Accident, File No. 7697, 16 February 1964, UH-1B, USABAAR, Fort Rucker, Alabama.
27. Aircraft Accident, File No. A866, 12 November 1964, UH-1B, USABAAR, Fort Rucker, Alabama.
28. Aircraft Accident, File No. D726, 4 February 1966, OH-23D, USABAAR, Fort Rucker, Alabama.
29. Aircraft Accident, File No. 5322, 26 October 1962, OH-13H, USABAAR, Fort Rucker, Alabama.
30. Aircraft Accident, File No. 7696, 15 February 1964, CH-34C, USABAAR, Fort Rucker, Alabama.

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